Human Biomonitoring of Arsenic and Antimony in Case of an Elevated Geogenic Exposure

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Abstract

Part of the northern Palatinate region in Germany is characterized by elevated levels of arsenic and antimony in the soil due to the presence of ore sources and former mining activities. In a biomonitoring study, 218 residents were investigated for a putative increased intake of these elements. Seventy-six nonexposed subjects in a rural region in south lower Saxony were chosen as the reference group. Urine and scalp hair samples were obtained as surrogates to determine the internal exposures to arsenic and antimony. The analyses were performed using graphite furnace atomic absorption spectrometry except for arsenic in urine, which was determined by the hydride technique. This method does not detect organoarsenicals from seafood, which are not toxicologically relevant. In the northern Palatinate subjects, slightly elevated arsenic contents in urine and scalp hair (presumably not hazardous) could be correlated with an increased arsenic content in the soil. On the other hand, the results did not show a correlation between the antimony contents in the soil of the housing area and those in urine and hair. Except for antimony in scalp hair, age tended to be associated with internal exposures to arsenic and antimony in both study groups. Consumption of seafood had a slight impact on the level of urinary arsenic, which is indicative of the presence of low quantities of inorganic arsenicals and dimethylarsinic acid in seafood. The arsenic and antimony contents in scalp hair were positively correlated with the 24-hr arsenic excretion in urine. However, antimony in scalp hair was not correlated with seafood consumption as was arsenic in scalp hair and in urine. This indicated the existence of unidentified common pathways of exposure contributing to the alimentary body burden. Short time peaks in the 24-hr excretion of arsenic in urine, which could not be assigned to a high consumption of seafood, were detected for six study participants. This suggests that additional factors relevant in the exposure to arsenic are still unidentified. **Key words** : arsenic, antimony, human biomonitoring, scalp hair, urine.

Introduction

Inorganic arsenic is well known as an environmental carcinogen. Reports from several countries show that an elevated exposure to arsenic, mainly through ingestion of arsenic-contaminated drinking water, is associated with several diseases, especially neoplasia. Increased incidences of skin, lung, liver, bladder, and kidney cancers and cardiovascular phenomena such as blackfoot disease could be identified (1 - 6). On the other hand, inhalation of arsenic, relevant mainly in workplaces, was shown to increase the risk of mainly lung cancer (7 , 8). Recently, evidence for increased risks of other types of cancers, mainly located in bone and kidney, was reported (9). In addition, increased rates of lung and skin cancers were noticed in winegrowers consuming wine contaminated with arsenic pesticides (10). Biomarkers of effect such as sister chromatid exchanges, micronuclei, and chromosomal aberrations were found at increased levels after elevated environmental exposure to arsenic (11 - 13). Moreover, several studies report an increased exposure to arsenic due to its release in the air from smelting activities (14 - 17).

Arsenic is a naturally occuring element found at relatively high levels in some drinking water sources and in soils. On the other hand, antimony is less widely distributed in the environment (18 , 19) but, like arsenic, it is known to be a genotoxic element in vitro and in vivo (20 , 21) and has been shown to cause lung tumors in female rats (22). However, it is not known whether antimony is carcinogenic to humans (23 , 24). Reports on elevated human exposure to inorganic antimonial compounds are of occupational exposures only (24 - 27). Knowledge is scarce concerning the transfer of antimony from the environment to humans and the related hazards to human health.

Soil contamination with arsenic and antimony in the northern Palatinate region in midwestern Germany is due to the presence of fahlore (copper arsenic sulfides and copper antimony sulfides; gray copper) sources. Cinnabar ore (mercury sulfide) is also found in these sources. A large range of concentrations of elements in the soil exists even in small areas because, in former centuries, intense mining activities caused elements to be unhomogenously distributed as rubble. Today, the region is characterized by housing and agriculture. In a biomarker study, the transfer of mercury from the environment to the residents could not be detected (19). The purpose of the present study was to investigate the transfer of arsenic and antimony from the environment to humans in the northern Palatinate region. Unlike the studies on arsenic previously described in which the main sources of exposure were arsenic-contaminated drinking water and industrial emissions, this study focuses on soil contaminated with arsenic and antimony as the main source of exposure.

Because humans excrete arsenic and antimony mainly via the kidneys (28 - 30), urinary concentrations were used as valid biomarkers of exposure. Biomonitoring of scalp hair was performed as additional screening to record cumulative exposures.

Methods

Study design and study population . This study was preceded by a project that sought to determine the contents of arsenic and antimony in soil and in plant and animal samples from the northern Palatinate region of Germany. Residents for whom the soil contents of arsenic and antimony in their housing areas were known (one to three soil samples per individual) were asked to participate in the study. To minimize a selection bias, a maximum participation rate was achieved by convincing those residents who did not reply to our first written request to participate. Nonexposed subjects from a rural area in south lower Saxony (Germany) were chosen as the reference group.

A six-page questionnaire served to assess factors of interest and confounding variables. All study subjects were interviewed concerning demographic characteristics, tobacco smoking, and alcohol drinking habits, and medical, occupational, and residential histories. Information on average and recent consumption of seafood, wild mushrooms and game, home grown vegetables, poultry, and eggs was requested throughout the questionnaire. A standardized analysis served to assign exact scores to the extent of seafood and home-grown produce consumption. For example, concerning seafood consumption, we asked how often seafood had been eaten during the previous week, when it had been eaten the last time, and how often in general seafood was eaten. We assigned 3 points to every meal of seafood. The examinations and collection of urine and scalp hair (50-100 mg, sampled occipitally with a length of 3-5 cm) were performed from June to September in the homes of the study participants. Collection of 24-hr urine was deemed appropriate to determine metal/metalloid biomarkers (31); relating these biomarkers to urine creatinine could lead to decreased accuracy of data (32). During the following weekend, participants of the study collected 24-hr urine in flasks containing 50 ml 60% acetic acid (suprapure) for stabilization. All flasks and other materials used had been previously tested and were free from any detectable amounts of arsenic and antimony. The samples were portioned and kept frozen at -20°C until atomic absorption analysis was performed. Urine creatinine was determined with the help of purchased test kits. Fourteen adult urine samples with a volume of less than 0.75 l/24 hr and a creatinine content of less than 0.5 g/l urine were considered non-24 hr urine and therefore excluded from the study evaluations. Soil data for 10 subjects from the exposed collective was not available, and we could only obtain hair samples from children who were not toilet trained. For these reasons, group numbers given in the tables and figures may differ slightly. The committee of ethics of the University of Goettingen gave written consent to the study design and proceedings.

Soil and scalp hair samples . Soil samples were taken from a 0-30-cm level, mixed, crushed (particle size <0.01 mm), and decomposed in 1:1 (v/v) nitric acid/sulfuric acid and detected by atomic absorption spectroscopy (AAS) as described below. Additional measurements were performed for a number of samples after the soil had been sieved; in this case the fraction with a particle size of less than 2 mm was used for analysis.

Hair samples were broken down in a closed system using a microwave apparatus (MLS mega 1200; MLS Leutkirch, Germany) with 25-50 mg hair added to 1 ml 65% (v/v) nitric acid and 0.5 ml 30% (v/v) hydrogen peroxide. The samples were mineralized with 450 W for 10 min. The hair samples were not rinsed before analysis because of the well-known impossibility of removing an external contamination without reduction of their internal mineral content (33).

Atomic absorption spectrometry (AAS) . Arsenic in urine was determined by means of the hydride technique using a Perkin Elmer AAS 400 (Perkin Elmer, Ueberlingen, Germany) with deuterium background compensation and an MHS 10 hydride generator. This technique is deemed the best approach to determine the arsenic

species relevant to human toxicology because it only detects inorganic trivalent and pentavalent arsenicals, i.e., As(III), As (V), and the mono- (MMA; monomethylarsonic acid) and dimethylated species (DMA; dimethylarsinic acid) of arsenic. On the other hand, it does not detect arsenobetaine, arsenocholine, and other organoarsenicals from seafood, which leave the human body unchanged (*28,29,34*). As(V), As(III), and MMA are recovered to 100% with this method, and DMA to approximately 80%. Arsenic and antimony in scalp hair and antimony in urine were determined by the graphite furnace technique with an atomic absorption spectrometer (Perkin Elmer SIMAA 6000) with Zeeman background compensation. The detection limits were 0.5 µg/l for arsenic using hydride AAS and 0.5 µg/l (urine) and 0.005 µg/g (scalp hair) for arsenic and antimony using graphite furnace AAS. The corresponding replicate precisions were 3%, 5%, and 8%, respectively. Samples were analyzed in random order. Validity of the analyses was guaranteed by participation in a biannual interlaboratory quality control program organized by the German Society of Occupational Medicine for analyses in occupational and environmental toxicology and by internal and external standards (analytical grade) determined in each analytical run.

Statistical evaluations . Statistical evaluations were performed with the software Winstat 3.1 (Kalmia Company, Cambridge, MA) (*35*). AAS results below the limit of detection were included in the statistical evaluations as an estimated 50% of the detection limit value.

Age, profession, sex, tobacco smoking, and seafood consumption were included in this study as possible confounding factors that can influence the contents of arsenic and antimony in urine and scalp hair. For the northern Palatinate subjects who were potentially exposed to higher levels of arsenic and antimony, we evaluated the soil contamination in their respective individual housing areas for any influence on the levels of urinary or scalp hair arsenic and antimony. Moreover, consumption of home-grown produce was included in the analysis.

Statistically significant outlying samples (p <0.05; no more than two for each element in urine or hair) were excluded from the study evaluation because they are not representative and they distorted the data. This proceeding did not change the statistical results, which had been proven by analysis using the whole data set. None of these outliers could point to any factor of interest in an individual analysis, and the source of elevated exposure of these subjects could not be identified.

In general, the statistical evaluations were conducted comparing the study subjects by region and by sex. Selected confounding factors like seafood consumption, sex, and age were included in an additional evaluation in which the two study collectives were combined. In case of equal sex distribution between strata, results are shown without stratification by sex for reasons of clarity. Multiple regression analyses were performed after logarithmic transformation, in which case the Pearson correlation coefficient is given.

Results

None of the study participants had an occupation that involved an elevated exposure to arsenic, antimony, or other heavy metals. The drinking water analyses conducted during the study period showed arsenic and antimony contents that were generally below 0.015 mg As/l and 0.002 mg Sb/l. Small drinking water systems and private wells used for drinking water had been included for the routine measurements. Thus, elevated exposures to arsenic and antimony by drinking water can be excluded; increased exposures could have been caused via the soil and home-grown produce only.

Special attention was given to skin conditions in the arsenic-exposed collective. Two subjects had dermatological manifestations. One of these subjects agreed to an additional examination by a dermatologist, and arsenic was excluded as the cause of his skin manifestation. No further indication of any adverse health effect that could be attributed to arsenic and antimony was found among the study participants.

Table 1. Range of arsenic and antimony in northern Palatinate soil versus natural range soil contents

	Natural range	Northern Palatinate	
		Total contents[a]	Soil (particle size <2 mm)[b]
Arsenic	2–20	<2–605	76–592
Antimony	<0.1–0.5	<0.2–776	19–266

Values are given in milligrams per kilogram dry matter.
[a]Total soil contents in the housing area.
[b]Data from one highly contaminated village only (Stahlberg); soil samples were sieved before analysis.

Compared to its natural range, high concentrations of arsenic and antimony are present in the northern Palatinate soil (Table 1). The contaminated soil in northern Palatinate is greatly scattered because of mining activities in the past that distributed these elements as rubble. On the other hand, soil samples from our south lower Saxony reference area revealed nonelevated concentrations of arsenic and antimony (data not shown).

The exposed group consisted of 218 people from the northern Palatinate region and the reference group of 76 people from south lower Saxony. Their general characteristics are shown in Table 2. A slightly higher percentage of people from south lower Saxony (67%) was willing to participate in the study in comparison to northern Palatinate. Study subjects from both regions had long residence times, with means of 29 and 23 years. Age range and smoking habits showed a similar distribution among the two groups. A higher number of older people in northern Palatinate participated in the study than in south lower Saxony, indicated by a median age of 53 versus 45 years, respectively.

Table 2. General characteristics of study subjects by region		
	Northern Palatinate	South lower Saxony
Participation rate (%)	60	67
Number of subjects	218	76
Female	121	38
Male	97	38
Mean (median) age (years)	46.2 (53.0)	43.4 (45.0)
Age range (years)	1–89	2–84
Mean residence time (years)	29	23
Smokers	48	16
Ex-smokers	46	22
Nonsmokers	124	38

To gain data on the transfer from arsenic and antimony from the soil to humans, the northern Palatinate study participants were grouped into four strata depending on the arsenic and antimony contents found in the soil of their respective housing areas (Fig. 1 and Fig. 2). The classifications were natural range soil content (see Table 1), slightly elevated (20-50 mg As/kg soil or 0.5-5 mg Sb/kg soil), or contaminated (>50 mg As/kg soil or >5 mg Sb/kg soil) (36). A highly exposed subgroup was chosen with the help of the 90th percentile of all soil data available for this study. A slight but significant correlation was noticed between the 24-hr arsenic excretion in urine and the content of arsenic in the soil (Fig. 1); the same was noticed for scalp hair (Fig. 2). The results of the respective statistical evaluations performed on an individual basis are presented in Table 3. Neither urine nor scalp hair showed increasing antimony levels with increasing contents of antimony in the soil. When the extent of home-grown produce consumption was included in the multiple regression analysis, only the level of urinary arsenic was very slightly but significantly correlated with this factor (Table 3).
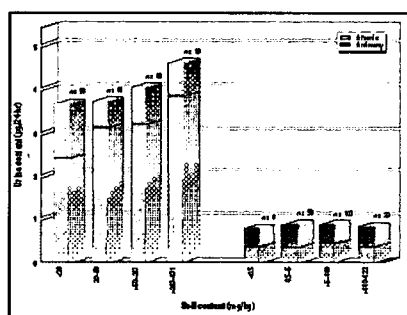

Figure 1 . Levels of urinary arsenic and antimony by soil contamination. The bar represents the mean, and the line in each bar indicates the median. Soil contamination was determined in the housing area of each exposed subject. The 90th percentile of the content of arsenic or antimony in the soil served as the criterion for selection of highly exposed persons.
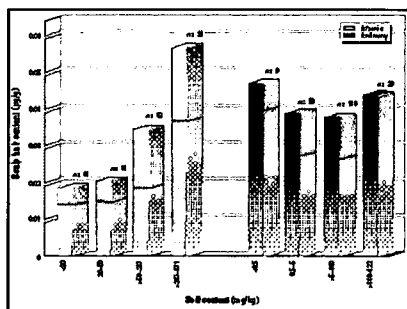

Figure 2 . Levels of scalp hair arsenic and antimony by soil contamination. The bar represents the mean, and the line in each bar indicates the median. Soil contamination was determined in the housing area of each exposed subject. The 90th percentile of the content of arsenic or antimony in the soil served as the criterion for the selection of highly exposed persons.

Table 3. Multiple linear regression analysis (additional model)

Parameter	Variable	r^2	p-Value
Arsenic in urine			
Northern Palatinate (n = 190)	Age	0.004	3×10^{-6}
	Soil content	0.032	0.0063
	Consumption of home-grown food	0.014	0.046
	Seafood	0.034	0.0046
	Total	0.164	
South lower Saxony (n = 74)	Sex	0.066	0.004
	Age	0.103	0.003
	Total	0.169	
Combined (n = 273) [a]	Sex	0.023	0.003
	Age	0.069	3×10^{-6}
	Seafood	0.044	1.2×10^{-4}
	Total	0.136	
Antimony in urine			
Northern Palatinate (n = 168)	Sex	0.036	0.004
	Seafood	0.016	0.044
	Total	0.051	
South lower Saxony (n = 74)	Age	0.06	0.03
	Total	0.06	
Combined (n = 272) [a]	Sex	0.025	0.009
	Total	0.025	
Arsenic in scalp hair			
Northern Palatinate (n = 201)	Sex	0.014	0.0048
	Soil content	0.047	0.0009
	Seafood	0.034	0.005
	Total	0.096	
South lower Saxony (n = 74)	Sex	0.128	0.001
	Age	0.056	0.019
	Total	0.183	
Combined (n = 285) [a]	Sex	0.04	0.0005
	Total	0.04	

No significant correlation was seen in the analysis of antimony in scalp hair (n = 265).
[a] In the combined evaluation, the 10 persons from northern Palatinate from whom no soil data was available were included.

Surprisingly, the reference subjects showed significantly higher levels of urinary arsenic and antimony (Table 4). However, data of both groups correspond to normal range reference data described by others (*17* , *29* , *37 - 42*). In a separate analysis, the children from the northern Palatinate region did not show higher contents of arsenic or antimony in urine or in scalp hair than the children of south lower Saxony. Thus, a special hazard to these children by an increased intake of contaminated soil did not seem evident.

Table 4. Levels of urinary and scalp hair arsenic and antimony by region

	As in urine (µg/24 hr)		As in hair (µg/g)		Sb in urine (µg/24 hr)		Sb in hair (µg/g)	
	Palatinate	Saxony	Palatinate	Saxony	Palatinate	Saxony	Palatinate	Saxony
Median	3.21	6.20	0.016	0.053	0.48	1.11	0.028	0.044
Mean	3.96	7.59	0.028	0.069	0.66	1.53	0.038	0.080
Maximum	18.32	23.78	0.154	0.592	4.73	5.66	0.317	0.459
Minimum	<0.1	0.25	<0.006	0.013	<0.5	<0.5	<0.006	<0.006
Included	190	75	211	74	198	75	211	74
Outliers	1	1	2	2	2	1	2	2
Excluded as non-24-hr urine	13	1	–	–	13	1	–	–
(U-test two-sided)	p<0.001		p<0.001		p<0.001		p<0.001	

Table 5. Spearman rank correlations (combined analysis)

	Sb (hair)	As (urine)	Sb (urine)
As (hair)	0.44[a] n =285 p=3.8 × 10⁻¹⁵	0.28 n =273 p=2.5 × 10⁻⁶	0.13 n =272 p=0.018
Sb (hair)		0.12 n =273 p=0.030	0.05 n =272 p=0.20
As (urine)			0.18 n =272 p=0.002

[a] Values given are the correlation coefficient, the number of cases, and the statistical significance (one-sided) of the correlation.

Only arsenic in urine was significantly correlated with age in the multiple regression analysis (Table 3). However, when comparing the study participants over 18 years of age with the younger ones, we found that except for antimony in scalp hair, a lower level of urinary arsenic and antimony predominated among the young subjects ($p <0.001$ two-sided U -test for arsenic and antimony in urine and $p = 0.055$ for arsenic in scalp hair (Fig. 3).
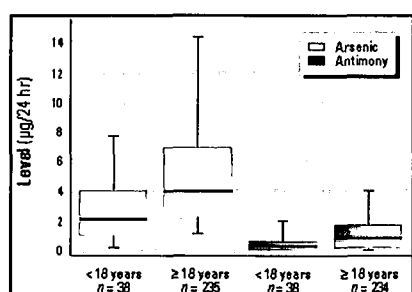

Figure 3 . Levels of urinary arsenic and antimony by age.

When the potentially exposed and the nonexposed groups were analyzed together in the statistical evaluation, the contents of arsenic in urine were positively associated with the extent of seafood consumption (Spearman coefficient of correlation r = 0.31; p <0.001) (Fig. 4 and Table 3). These findings correspond with those of other authors (*14* , *40*).
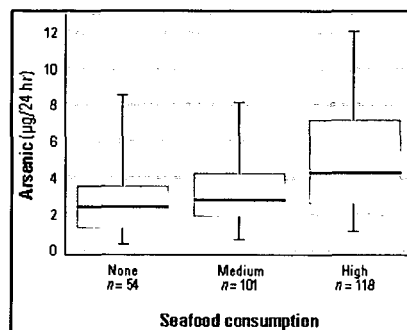

Figure 4 . Levels of urinary arsenic by seafood consumption.

The determination of elevated exposures to antimony is hindered by low antimony body burdens in the population in general. In this study, this is indicated by a high percentage of samples below the limit of analytical detection. In 89 out of 196 samples from the northern Palatinate collective and 57 out of 75 urine samples from the reference group, antimony levels were found to be below 0.5 µg /l in urine.

In the collective-combined multiple regression analysis, male sex was positively associated with the contents of arsenic and antimony in urine and the contents of arsenic in scalp hair (Table 3). Antimony in scalp hair was not associated with sex, age, or with any other factor included in the analysis. Further associations in the multiple regression analysis could be found for arsenic in urine, which was correlated with seafood consumption and tended to be related with age. Consumption of home-grown produce revealed an association with arsenic in urine in the northern Palatinate collective only. Furthermore, the content of arsenic in the soil was associated with the 24-hr excretion of arsenic in urine and with the content of arsenic in scalp hair samples.

The arsenic contents in scalp hair were correlated with the antimony contents in scalp hair in the combined evaluation (Spearman correlation coefficient r = 0.44, p <0.001) (Fig. 5 and Table 5), although antimony in scalp hair was not associated with any of the factors included in the analysis (Table 5). Thus, there are unidentified sources, maybe dietary factors other than seafood, that cause both arsenic and antimony to be ingested in higher amounts. Furthermore, the arsenic contents in urine and scalp hair were positively correlated (Table 5), which is in agreement with another report (*15*).
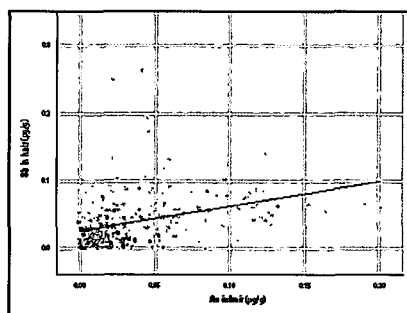

Figure 5 . Correlation arsenic and antimony in scalp hair (r = 0.44; n = 285).

Tobacco smoking did not have any influence on the contents of arsenic and antimony in urine or hair. Our results agree with other biomonitoring studies (*17* , *40* , *43*) and with recent trace element analyses of cigarette smoke that show low arsenic and antimony contents (*44*).

Discussion

Because of stringent environmental laws in industrialized countries, contamination levels of public concern are often too low to cause an increase in the incidence of disease that is large enough to be detected by epidemiological studies. Thus, the determination of biomarkers of exposure is a more appropriate method of assessment than to take the respective diseases as an endpoint.

Hydride AAS is the analytical method recommended to determine arsenic species of toxicological relevance, i.e., As(V), As (III), MMA, and DMA. Organoarsenicals and trimethylated arsenic compounds can be found at high concentrations in seafood, but they leave the human body metabolically unchanged. These species are thus not relevant for toxicological risk assessment and cannot be detected with the hydride technique (28 , 29). However, in this study we found an association between seafood consumption and increased arsenic contents in urine, which had been described previously (14 , 40). This may be explained by the prevalence of low quantities of inorganic arsenicals and DMA in seafood [reviewed by Phillips (45)]. Certain marine species like crustacea or shellfish may have a greater impact on the release of inorganic arsenic (40 , 46). Freshwater fish seem to have lower arsenic contents, as do bottomfeeding fish and crustacea (47 , 48). Additionally, it seems likely that a certain portion of DMA or even inorganic arsenic can be released from seafood organoarsenicals (46).

Consumption of fish seems to play a more important part in the internal exposure to toxicologically relevant arsenicals than previously thought. We, like others (14 , 49), think that when determining arsenic as biomarker, seafood consumption should be included as a confounding variable, even when there is a low consumption of seafood in a population, as was the case in this study. Because inorganic arsenic is some orders of magnitude more genotoxic than DMA (50 , 51), it is important to know which species of arsenic are released from seafood in high amounts and whether differences exist depending on the type of seafood. Further research is necessary to determine the impact of seafood consumption on the exposure to toxicologically relevant arsenicals.

The reference subjects showed a significantly higher arsenic excretion in urine combined with a significantly higher mean score for seafood consumption (medians 15.0 vs. 9.0; ranges 0-42 and 0-45, respectively; p = 0.001, two-sided U -test). Thus, the differences in arsenic excretion between the two study groups may be explained by differences in seafood consumption. In contrast, the differences in antimony excretion in urine between the two study groups, as well as after stratification by sex, cannot be explained by differences in fish consumption because antimony in general was not associated with this factor in the statistical analysis. Unidentified regional differences in dietary habits and differing contents of antimony in food may be more plausible reasons.

Six subjects (5-56 years of age), among them one from northern Palatinate, showed a drastic short-time peak of arsenic in urine up to maximum values of 140 µg/l. This short-time peak of urinary arsenic was documented by others (40 , 52 , 53) and was suggested to be caused by enhanced consumption of seafood (52). Our findings, together with those of others (14 , 40), showed that seafood consumption is associated with but does not lead to an extreme increase in the urinary excretion of arsenic. Moreover, the six subjects were moderate consumers of seafood (range 1.5-18; median 9.0); one of these six had eaten fish the day before urine sampling, and the other five had not eaten seafood the last 10 days. There was no other source known for their elevated exposure to arsenic. We conclude that there may be other, presumably dietary, sources of arsenic, which still need to be identified.

Previous studies found a sex-specific higher urinary excretion of arsenic for men (17 , 42). Buchet et al. (17) proposed that male persons had higher levels of urinary arsenic because they absorb more dust-borne arsenic than females because they may do more gardening and farming. Different sex-related toxicokinetics or dietary habits were suggested as further possible reasons (17). However, these authors had not investigated whether there were sex differences in seafood consumption. In the present study, the score for seafood consumption proved to be not significantly different between the sexes [medians were 9.0 vs. 9.0 (northern Palatinate) and 16.5 vs. 15.0 (south lower Saxony) for females and males, respectively]. Thus, seafood consumption is presumably not the reason for the observed sex differences in arsenic excretion. Also, in this study we noticed that men seemed to have a higher burden of antimony in comparison to women.

We, like others (14 , 17), found that arsenic excretion in urine was slightly associated with age. With respect to the comparatively short biological half-life of arsenic of 30-40 hr (28 , 29 , 54 , 55), it cannot be explained why older people showed higher concentrations of arsenic and antimony in urine and in scalp hair.

In Tacoma, Washington, residents were exposed to arsenic via a former copper smelter (14), but an increase in arsenic excretion was found mainly in children up to 6 years of age living at a maximum distance of a half-mile from the smelter. Moreover, twofold and 10-fold elevated levels of arsenic in urine and scalp hair, respectively, were reported for children exposed by smelter emissions in Mexico (15). Binder et al. (56) reported elevated arsenic burdens only in children living near a former copper smelter. In contrast, in a biomarker study conducted by Hewitt et al. (57), no evidence for an increased body burden of arsenic was found in workers exposed to arsenic-contaminated soil. Ingestion of dust by hand-to-mouth contact seems to be the relevant exposure pathway (14); thus, the exposure may be higher for children than for adults because of ingestion of soil. Nevertheless, in the present study, a slight association between arsenic exposure and the levels of arsenic in urine as well as in scalp hair was also found for the adults.

The validity and quality of the data gained by scalp hair biomonitoring is not comparable to that gained by urine and blood biomonitoring. First of all, the analysis of scalp hair is not standardized. Its validity has a major drawback in that a scatter of data is caused by various factors such as length and color of hair and the use of hair coloring and permanents. Nevertheless, on the level of intergroup differentiation, it is a valuable screening tool. In this study, the results from scalp hair biomonitoring confirm the results of urine as biomarker. Scalp hair proved to be affected by increased arsenic contents

in the soil, as was arsenic excretion in urine. External contamination of hair is not likely to have been relevant because scalp hair did not reveal increasing contents of antimony with increasing exposure to antimony-contaminated soil.

Gastrointestinal absorption of antimony (5-20%) is far lower than of arsenic (60-80%) (*28* , *54* , *55* , *58* - *60*). This could explain why the internal exposures to antimony were not associated with increasing exposure to antimony-contaminated soil. However, it has to be taken into account that very little is known about the enteral absorption of these elements when they are soil bound.

The transfer rate of arsenic and antimony to vegetables and animals was found to be low in northern Palatinate (L. Steubing, personal communication). Furthermore, we recently found that sheep bred on grounds contaminated with arsenic and antimony did not reveal elevated contents of these elements in blood and wool or was there evidence of an increased DNA damage (*18*). The results of this study indicate that mere exposure to contaminated soil in the northern Palatinate area did not lead to a severe human exposure. However, it can be presumed that, in case of geogenic exposure, arsenic is more easily transferred from the environment to man than is antimony. Nevertheless, the transfer rate is low and leads to slightly, yet presumably not hazardous, elevated arsenic contents in urine and scalp hair. We can justly presume that an elevated risk of cancer should not be expected for the residents of the northern Palatinate region.

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